STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

PROFILOGRAPH STUDY - TOPEKA TEST ROAD

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State of California
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MATERIALS AND RESEARCH DEPARTMENT

July 16, 1956

PROFILOGRAPH STUDY

OF

TOPEKA TEST ROAD

Using Manual Profilograph

of

California Division of Highways

Field work by . . . . D. L. Spellman

Analysis and Report by. . . . . Bailey Tremper
and
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The Topeka Test Road was constructed in 1949. The following information is taken from "Roads and Streets", September, 1949. The test road is a 4-lane divided highway 4-1/2 miles in length on U.S. 75 just south of Topeka, Kansas. It is constructed of portland cement concrete of 9-inch uniform thickness on a 6-inch granular subbase. Expansion joints are spaced at 500 feet and contraction joints at 20 feet. The longitudinal center joint was formed after the concrete was placed and contains premolded joint material and tie bars. 3/4-inch marginal bars, treated to destroy bond are located 4 inches from each pavement edge.

The pavement is divided into experimental sections about 1000 feet in length. The variables include:

3 cements, "old-fashioned", "modern" and "modern, coarse-ground," numbered 1, 2 and 3 respectively for purposes of reference.

2 maximum sizes of aggregate, 1 inch and 2 inch

2 curing methods, 1924 specifications, and 1949 specifications.

12 sections each embodying one of the above variables constitute a round. A total of three rounds or 36 sections was placed.

On May 28, 1956, profilograms of 24 sections comprising two rounds were obtained with the 25-foot, manual profilograph of the California Division of Highways. This report summarizes the pavement condition as indicated by the profilograph record.

Figure 1 contains tracings of the recorded profilogram of sections 160 feet in length. The upper three pairs

of traces are fairly representative of those sections of average roughness for each of the three cements. The fourth pair of curves is an example of extreme roughness and the lower pair, of exceptional smoothness.

Duplicate profiles were obtained, the first in the morning between 6 AM and 9 AM and the second in the afternoon between 1 PM and 4 PM. In all cases the profilograph was operated along a line about 30 inches from the outer edge of the pavement, that is, at the approximate location of the outer wheel track of the outer lane. The morning and afternoon profiles are remarkably similar in shape, an indication that the recorded trace can be duplicated on successive runs.

The predominant feature shown by the profilograms is an upward curling of the slabs at each end. Of the 1200 slabs surveyed, only 40, or 3 percent, have a downward curl.

Pavement temperatures were measured with a dial thermometer attached to the top surface and by a stem thermometer inserted slightly under the outer edge of the slab at its junction with the subgrade. Atmospheric and pavement temperatures are shown in Table I.

At 6:30 AM the top of the pavement was 9 degrees cooler than the bottom. At about 7:45 AM top and bottom temperatures were equal. At 1:40 PM the top surface was 26 degrees warmer than the bottom. As measured from the profilograms the amount of curl per slab at 6:30 AM was reduced by about 25 percent at 1:40 PM. It appears, therefore that a major part of the observed curling is present in the pavement at all times.

A few of the joints show slight to moderate faulting, up to about 0.3 inch, but in the main the faulting is not measurable from the profilograms.

The roughness of each section was computed from its AM profilogram. The total upward departure from a plane was computed and this amount was multiplied by two to obtain the total upward and downward roughness. The result was converted to equivalent inches per mile. Computations made by different individuals checked closely. The Kansas Highway Commission operated its roughometer over the pavement at 7 AM of the day that the profilograph was operated.

The comparative roughness of each section as determined by the two instruments is plotted in Figure 2. It will be noted that in general, the roughness indicated by the profilograph exceeds that of the roughometer by about 10 inches per mile. In nine of the 24 sections the roughness indicated by

the profilograph exceeds that of the roughometer by more than 20 inches per mile. The roughometer shows section 34 to be the smoothest but the profilograph shows it to be of average roughness. Section 33 which is shown to be the roughest by roughometer is also of average roughness by profilograph estimate.

The following discussion deals with the roughness and the factors causing it as disclosed by the profilograms.

Table II lists the profilograph roughness of each test section. The most pronounced differential in average roughness occurs between cements 1 and 2, cement 2 showing 21 inches per mile, or 20 percent, greater roughness. Cement 3 is in an intermediate position. The two sizes of aggregate had a minor effect, if any, on roughness. The conditions of curing appear to have caused a differential of about 8 percent.

The total roughness of a pavement is caused by inequalities during construction, differential settlement at the two ends of the slab, faulting, and curling. Curling may be caused by unequal pressure of expansive soils or by warping due to directional drying. The amount of curling of each slab independently was measured from the profilograph traces. The curl was taken as the maximum departure of the low point of the slab from the plane passing through the two ends. As noted above, only three percent of the slabs showed an upward curl. In these cases the curl was recorded as zero. The measurement of slab curling is indicated by arrows in Figure 1.

Table III gives the average curl of the slab in each test section. The variations are similar in trend to that of total roughness. The greatest differential is between cements 1 and 2. The size of aggregate had little effect, but the curing conditions were significant in their effect.

The roughness due to curl in each slab is equal to twice the measured curl. There are 264 slabs per mile. The roughness per mile due to curl is 2 x curl x 264. It is possible, therefore, to separate the roughness due to curl from that caused by other factors. Some of the results are listed in Table IV.

The roughness due to causes other than curl is approximately constant throughout, thus showing that the main cause of differences in roughness is due to curl. Curling has caused approximately 70 percent of the total roughness. The determination of methods that will be effective in minimizing curl are thus shown to be of great importance in securing permanent smoothness in pavements.

The analysis shows that the characteristics of the cement are of major importance. The curl produced by Cement 2 is 125 percent of that produced by Cement 1.

Information regarding the properties of the three cements is contained in test results of the Long Time Cement Study reported by Waterworks Experiment Station. In this report, three cements identified as Nos. 19A, 19B and 19C are stated to be those used on the Topeka Test Road. An abstract of the test data is given in Table V. It is concluded that Cement 19A corresponds to the "old-fashioned" cement, No. 1, 19B to the "modern, coarse ground" cement, No. 3, and 19C to the "modern" cement, No. 2, as identified by the Kansas Highway Commission. The tests for drying shrinkage are of particular interest because, of all the tests made, that for drying shrinkage appears to have the most significance with respect to the development of curling in pavement slabs.

Figure 3 shows the total roughness developed in the Topeka test sections, the roughness due to slab curling alone and the test results for drying shrinkage. It is obvious that the trend of the plotted curves is in the same direction for pavement roughness and drying shrinkage. The significance of this finding would of course, be greater if more cements were involved.

It will be noted that the three cements contain similar amounts of C_3A and alkalies, the compounds that have the greatest effect on drying shrinkage. The three cements were manufactured in the same factory. It seems probable that among a greater number of cements, produced in different mills and with a wider variation in C_3A and alkalies, the differential in curling of pavement slabs would have been greater.

Differences in the curing procedures are also shown to have a significant effect on the development of curling. The 1924 method caused 20 percent more curl than the 1949 method. Complete details of the two curing methods used are not described in literature presently available for reference. It is stated however, in "Roads and Streets" that the cement content under the 1924 method was 1.60 bbl. per cu. yd. and under the 1949 method, 1.40 bbl. per cu. yd. Since richer mixes are known to cause greater drying shrinkage, and greater warping during directional drying, it is possible that the lower cement content alone was responsible for reduced curling under the 1949 method.

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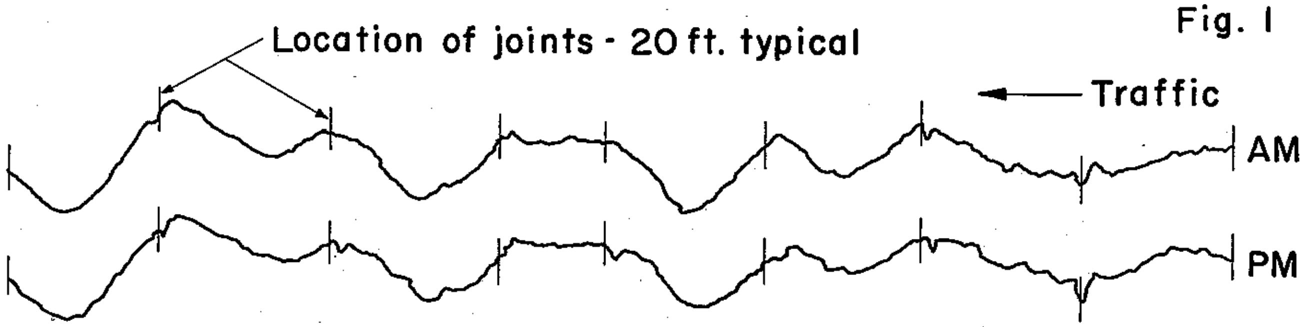
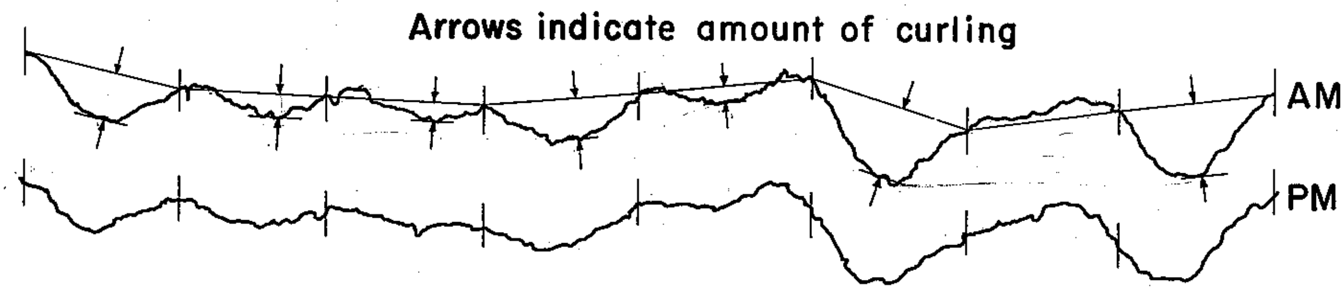
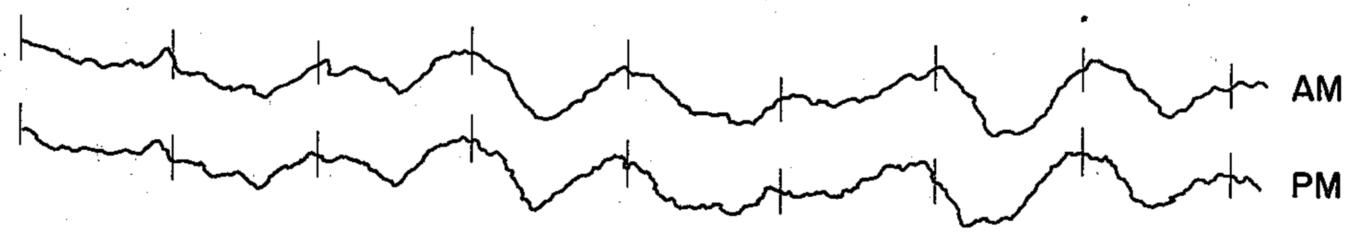
Fig. 1



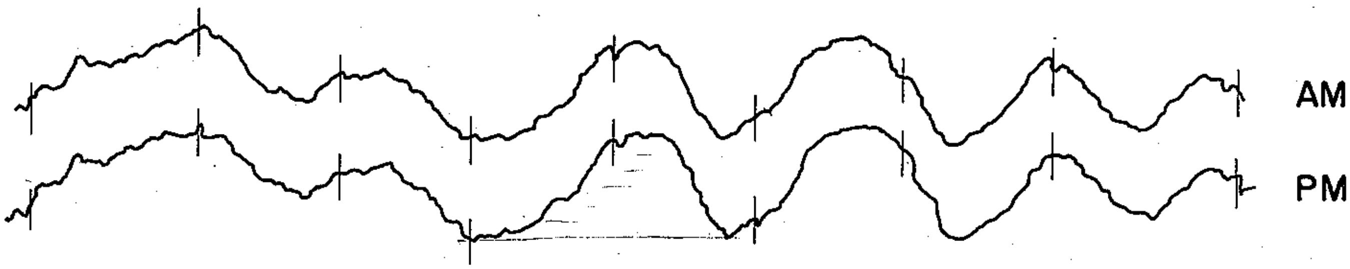
Section 19 Cement 2 1" Aggt. 1924 Curing 124" per mile



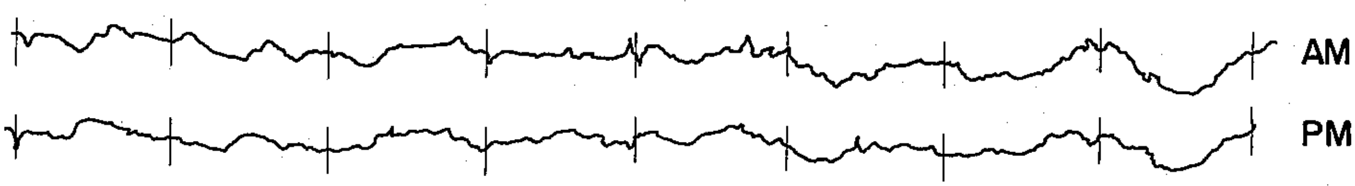
Section 22 Cement 3 1" Aggt. 1924 Curing 108" per mile



Section 1 Cement 1 1" Aggt. 1949 Curing 106" per mile

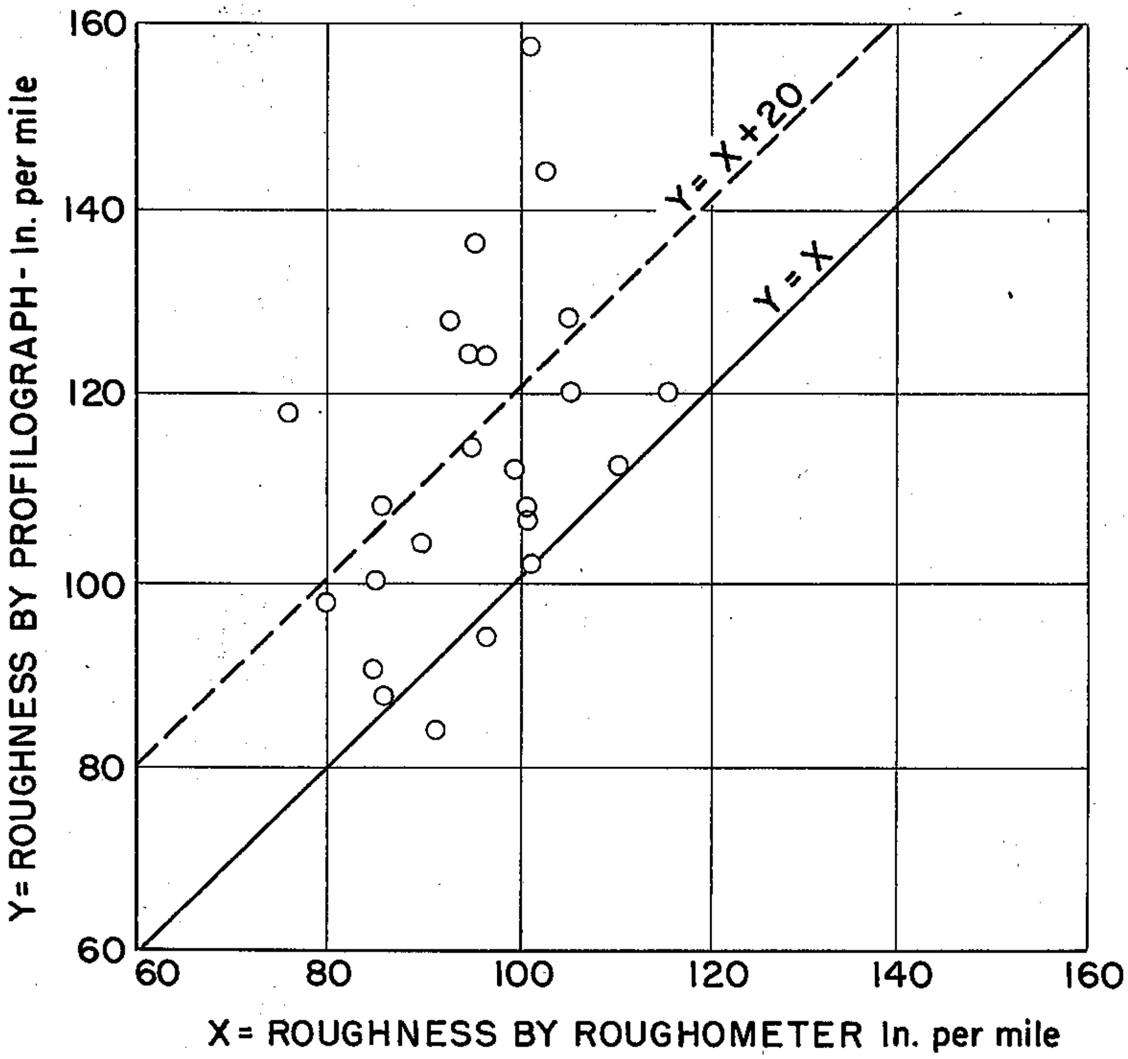


Section 33 Cement 2 1" Aggt. 1924 Curing 158" per mile



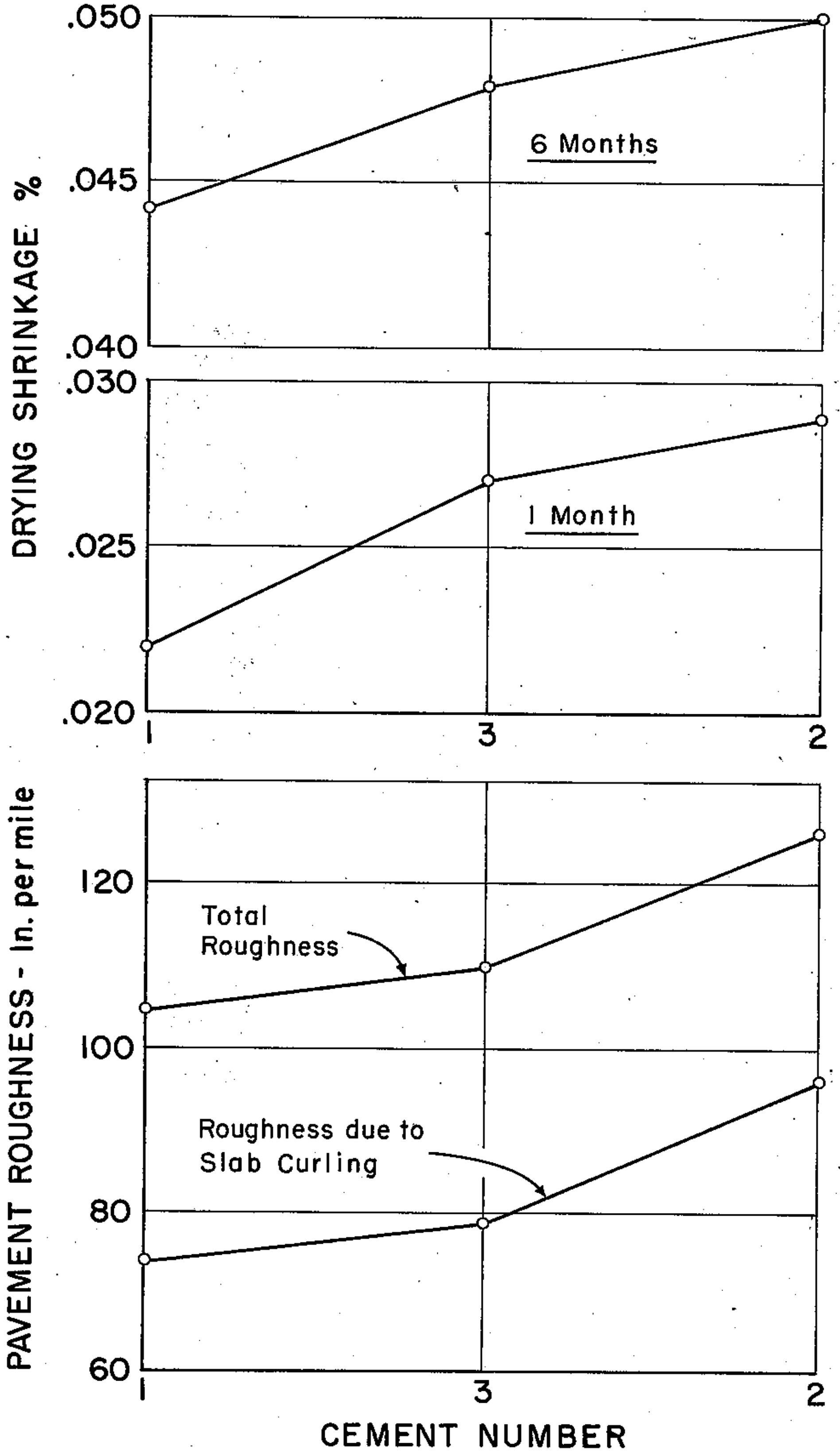
Section 27 Cement 1 2" Aggt. 1924 Curing 84" per mile

SCALE: 1" = 2.5' Horizontal
1" = 1" Vertical



COMPARATIVE ROUGHNESS OF TEST SECTIONS AS INDICATED BY ROUGHOMETER AND PROFILOGRAPH

Fig. 3



DRYING SHRINKAGE AND PAVEMENT ROUGHNESS AS RELATED TO CEMENT

TABLE I

Temperature and Relative Humidity Record

During Operation of Profilograph

Date	Time	Air Temperatures, °F		Relative Humidity	Pavement Temp., °F	
		Dry Bulb	Wet Bulb	%	Top	Bottom
May 28	6:30 A	68	65	85	65	74
	7:10 A	70	66	81	69	75
	8:00 A	72	66	73	82	76
	8:45 A	76	74	91	85	75
	1:15 P	86	73	53	100	78
	1:40 P	87	73	48	104	78
	2:20 P	89	75	51		
	3:20 P				108	

TABLE II

Roughness of Test Sections is Computed from Profilogram
inches per mile

Cement No.	1				2				3			
Curing Spec'ns.	1924		1949		1924		1949		1924		1949	
Aggregate Size	1"	2"	1"	2"	1"	2"	1"	2"	1"	2"	1"	2"
Roughness, inches per mile	106 108 107	84 128 106	104 102 103	98 112 105	124 158 141	136 144 140	100 120 110	114 112 113	128 120 124	88 94 91	118 108 113	9[illegible] 12[illegible] 10[illegible]
Avg. for Cements	105				126				109			
Avg. for Curing	1924 Specifications 118 1949 Specifications 109											
Avg. for Aggr.	1-inch Max. size 116 2-inch Max. size 110											

TABLE III

Curling of Slab as Measured from Profilogram
inches per slab

Cement No.	1				2				3			
Curing Spec'ns.	1924		1949		1924		1949		1924		1949	
Aggregate Size	1"	2"	1"	2"	1"	2"	1"	2"	1"	2"	1"	2"
Curling, inches per slab	.138 .145 .141	.110 .184 .147	.139 .116 .128	.130 .145 .138	.200 .226 .213	.202 .220 .211	.146 .164 .155	.148 .147 .148	.211 .147 .179	.100 .161 .131	.116 .155 .136	.14[illegible] .14[illegible] .14[illegible]
Average for Cements	.139				.182				.147			
Avg. for Curing	1924 Specifications .171 1949 Specifications .141											
Avg. for Aggr.	1" Maximum size .159 2" Maximum size .153											

TABLE IV

Analysis of Causes of Roughness
inches per mile

	Total Roughness	Roughness due to curl	Roughness due to other causes
Cement 1	105	74	31
Cement 2	126	96	30
Cement 3	109	78	31
1924 Curing	118	91	27
1949 Curing	109	75	34
1" Max. Aggt.	116	84	32
2" Max. Aggt.	110	81	29

TABLE V

Abstract of Test Data of Topeka Test Road Cements as reported by Waterworks Experiment Station

No.	C_3S	C_2S	C_3A	C_4AF	SO_3	Na_2O	K_2O	Na_2O Equiv.	Specific Surface Wagner	Specific Surface Blaine
19A	37.4	35.8	8.9	9.7	1.9	0.32	0.71	0.79	1490	2045
19B	48.2	25.9	9.6	8.5	1.9	0.30	0.54	0.66	1540	2525
19C	49.2	22.6	9.9	9.4	2.4	0.31	0.60	0.70	1710	3265

Drying Shrinkage 2x2x11-in. Prisms

% after drying for period indicated

No.	1 Month	6 Months
19A	0.022	0.044
19B	0.027	0.048
19C	0.029	0.050